On the Air

Technical Notes on Important Air Quality Issues

October 2003

The Changing Face of Ozone Management

Science: Ground-level ozone pollution presents a complex air quality management issue. TVA conducted research as part of the Southern Oxidant Studies during the 1990s to improve the understanding of factors controlling ozone pollution. These studies confirmed that, in the southeastern U.S., abundant natural biogenic sources (vegetation) dominate emissions of one class of ozone precursors, volatile organic compounds (VOCs). As a consequence, ozone management must be achieved primarily through control of NO_x emissions, the principal anthropogenic precursor of ozone.

Policy: Improved understanding of ozone production and transport has led to significant changes in environmental management strategies to reduce ozone pollution. Nevertheless, meeting the recently revised national 8-hour ozone standard will prove a considerable challenge. There is now increased emphasis on NO_x controls to help manage eastern ozone pollution.

Background

Most ozone (about 90 percent) is found high above the earth's surface. This "good" stratospheric ozone absorbs much of the sun's potentially damaging ultraviolet radiation. Ground-level ozone (called smog) can adversely affect health, crops, forests, and materials at sufficiently high concentrations. Smog can be produced in abundance on warm, stagnant, sunny days when oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and sunlight initiate a complex series of ozone-forming chemical reactions. Despite more than three decades of effort with billions of dollars invested in research and emissions controls, ozone remains a problem.

One of six "criteria" pollutants regulated under the Clean Air Act, ozone has a National Ambient Air Quality Standard (NAAQS). The current ozone NAAQS sets 1- and 8-hour standards on outdoor ozone concentrations. The 1-hour standard is 120 parts per billion (ppb) and the 8-hour standard is 80 ppb. In the Tennessee Valley, peak 1-hour ozone concentrations have improved (declined) by about nine percent since 1979, while peak 8-hour concentrations have not changed significantly during this period. The 1-hour standard has been attained throughout the Tennessee Valley region, suggesting that abatement programs have been partially successful. Indeed, VOC emissions caused by human activities have

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declined in the same period. NO_x emissions in the Tennessee Valley have declined over the last five years, but that trend follows a small increase in the 1980s and 1990s. Thus, over the past 20 years NO_x emissions have remained largely unchanged. Similarly, emissions measured per unit of activity have decreased, e.g. NO_x and VOC emissions per vehicle mile, but some of these benefits have been offset by growth in vehicle-miles-travelled.

Ozone Nonattainment

Areas failing to meet the ozone NAAQS become designated as nonattainment areas. Once an area is so designated, state and local environmental regulatory programs are tasked with developing and applying "state implementation plans" to bring the area into attainment. These plans can have significant economic and social impacts. For instance, before industries can build or expand in a nonattainment area, they must convince nearby facilities to reduce their emissions of ozone-producing pollutants by an amount greater than the new or modified facility would emit. Other measures may include vehicle inspection and maintenance programs.

1. Ozone Management

Early ozone management strategies focused, almost exclusively, on limiting VOC emissions from on-road vehicles and from industries producing and storing VOCs (refineries, fuel transport and storage facilities, etc.). This strategy worked well in some urban areas, reducing the magnitude and frequency of excessive ozone levels. The number of ozone nonattainment areas based on the 1-hour standard dropped substantially.

In the southeastern U.S., however, vegetation is a significant source of natural (i.e. biogenic) VOC compounds. Hardwoods, particularly oaks, emit ozone-producing VOCs in abundance. Through the mid 1980s, biogenic VOCs were believed to contribute little to ozone formation. As a result of various research projects, the most of extensive of which were the Southern Oxidant Studies conducted in the 1990s, we now know that biogenic VOCs far exceed human-caused VOC emissions in the eastern U.S. In fact, according to recent estimates by the U.S. Environmental Protection Agency, biogenic sources account for 60 percent of all U.S. VOC emissions each year. The importance of natural VOC emissions in ozone production is further amplified, when we consider that natural VOCs account for about 75 percent of VOC emissions in the ozone season (April through September). As a consequence, there is now an increased emphasis on NO_x controls to help manage eastern ozone pollution. While strategies for managing urban ozone should respond to both VOC and NO_x emissions reductions, rural ozone management should focus on NO_x.

2. NO_x Emissions

Recent efforts to lower NO_x emissions have largely focused on the electric utility sector, which provides about 25 percent of human-caused NO_x emissions in the U.S. The Southern Oxidant Studies revealed that ozone production chemistry in rural power plant plumes is quite different from that in urban areas. In urban areas, mobile sources typically dominate both NO_x and VOC emissions. Since these sources co-emit both ozone-precursors, when conditions are right, urban ozone is quickly formed above and downwind of the urban area (Figure 1). This limits the effectiveness of urban management strategies that focus chiefly on power plant emissions. Power plants, in contrast to vehicles, emit considerable NO_x but almost no VOCs. Consequently, ozone is formed only after the NO_x-rich plume mixes with VOCs from largely natural sources in the surrounding air. Near the power plant stack, NO_x concentrations are so high that ozone is actually removed from the plume. As the plume dilutes, however, NO_x mixes with VOCs at the plume edge and excess ozone is produced. Eventually ozone production occurs across the well-mixed plume and resulting concentrations can be significantly higher than in the surrounding air. Production continues in rural areas until the NO_x is consumed or the sun goes down.

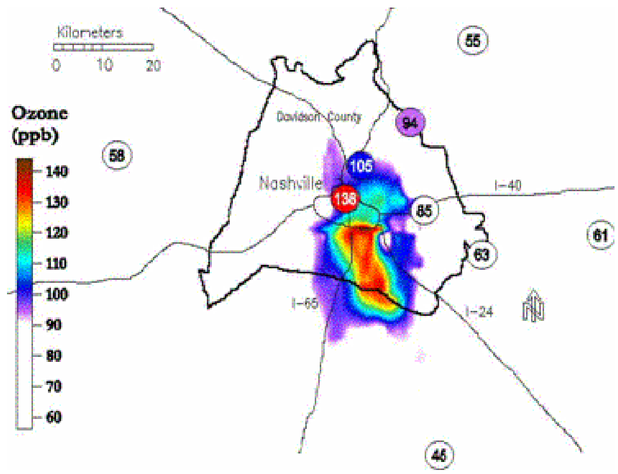

Figure 1. Nashville Urban Ozone Plume, July 12, 1995, illustrating rapid urban ozone formation downwind of the plume.

Ozone chemistry is nonlinear, which means that increases or decreases in precursor emissions are not necessarily accompanied by proportional changes in ozone levels. Research shows that ozone-production efficiency (i.e., molecules of ozone formed per molecule of NO_x) in a NO_x-rich power plant plume varies considerably depending on the size and location of the plant and transport conditions.

A comparison of two coal-fired power plants near Nashville found that, although the higher NO_x-emitting plant produced ozone, the increase above background levels was substantially less than that for the lower NO_x-emitting plant. Clearly, all NO_x sources are not created equal in terms of their ability to produce ozone. However, current ozone control strategies assume that all NO_x is created equal. To optimize emissions control costs, environmental regulators often give industries some flexibility in where NO_x emission reductions are achieved. This policy often results in controls being applied to the larger NO_x sources where the cost per ton of NO_x removed is lowest. However, this doesn't necessarily achieve the greatest reduction in ozone production.

3. Distributed Generation

The electric power industry is in the early stages of a restructuring that is designed to move the country away from a system of regional, centralized utilities to a more de-centralized competitive market that provides open access for wholesale, commercial and even residential customers.

Incentives that promote distributed generation have been included in electric utility restructuring bills currently before Congress. While there are many potential economic benefits associated with this approach, including increased reliability and reduced transmission losses, the potential impacts on air quality should also be considered.

For example, smaller natural-gas powered turbines appear to be an attractive option in the near term. These turbines have impressively low NO_x emission rates. However, model analyses suggest that spreading these emissions over large areas--especially rural areas--may result in more efficient ozone production per unit of

NO$_X$ emitted. This would result from the more frequent occurrence of the ideal mix of VOCs and NO$_X$ over a wider area. Consequently, some of the benefits associated with lower overall NO$_X$ emissions are likely to be offset by more efficient ozone production.

Complex Issues & Difficult Choices

Clearly the complex processes that control the formation and distribution of ground-level ozone challenge our environmental management strategies. The problem is further complicated by regional differences in emissions, geography and weather. The new 8-hour ozone standard, with its lower concentration limit and longer averaging time, highlights the need to extend the ozone-management perspective from a local to a more regional scale, placing a premium on cooperation among regions and states. The likely increase in ozone nonattainment areas (Figure 2), resulting from the 8-hour standard, will put additional pressure on regulators to reduce precursor emissions--a challenging proposition in the face of an ever-changing economy and plans to restructure the nation's energy system.

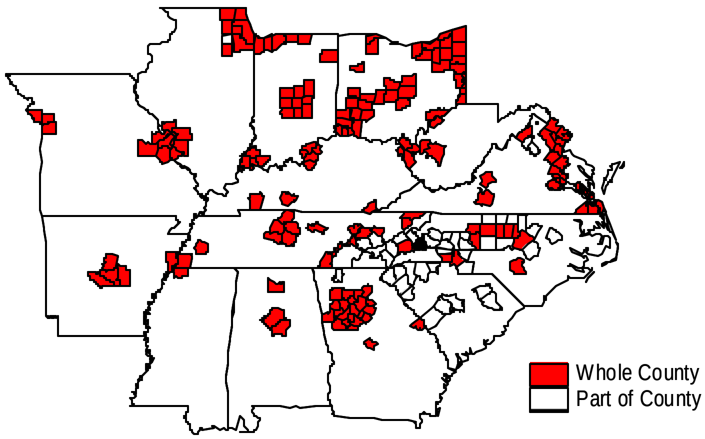

Figure 2. Potential Ozone Nonattainment Areas in Southeastern U.S. (2000-2002 Monitoring Data). Nonattainment counties are indicated in red. Only counties where data is available are shown.

Conclusions

The better understanding of ozone formation that research has made available has provided a "roadmap" to improved local and regional ozone management strategies:

- Urban ozone management should respond to both VOC and NO$_X$ emission reductions; rural ozone management should focus on NO$_X$ emission reductions.
- Policies should focus on achieving the greatest reduction in ozone production, which, because of the effects of source location and other factors, is not necessarily the same as achieving the greatest reduction in NO$_X$ emissions.
- The impact of distributed generation on ozone formation must be carefully evaluated since it may result in increased ozone production efficiency.

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